Active Surface Architectures of Large Radio Telescopes

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ABSTRACT

The active surface architectures of all three large radio telescopes either built or under active development are reviewed, with an emphasis on the recently completed Robert C. Byrd Green Bank Telescope.

INTRODUCTION

The first two large, dynamic, active surface radio telescopes (adjustments made continuously or on short-time intervals) were designed in the 1990's. The Robert C. Byrd Green Bank Telescope (GBT)[1, 2]; built by the National Radio Astronomy Observatory (NRAO), Radiation Systems Inc. (RSI, parts of which are now Lockheed Martin and VertexRSI) and Loral (now Lockheed Martin); in Green Bank, West Virginia, is a 100-meter offset paraboloid, for operation between 1 meter and 3 mm, completed in 2000. The Large Millimeter Telescope (LMT)[3]; a joint effort of the University of Massachusetts at Amherst and the Instituto Nacional de Astrofisica, Óptica, y Electrónica (INAOE) in Mexico, with engineering by VertexRSI and MAN Technologie; is a 50-meter telescope, for operation between 4-1 mm wavelength, being built in Puebla, Mexico, scheduled for completion in 2004. The Sardinia Radio Telescope (SRT)[4] is a 64-meter telescope that is still in the design phase, but plans are for an active surface. All architectures use motor-driven actuators to position high accuracy panels, but the GBT, LMT and SRT designs employ significantly different surface architectures. There are also a number of unique problems introduced by the asymmetric design of the GBToffset reflector.

The LMT will use 180 subframes (average of 10.9 m^2/subframe), with four actuators per subframe (720 total), to provide independent adjustment of each subframe. Microwave holography will be used to set the zero points for the actuators and to improve the finite element and temperature models. Dynamic adjustments will initially be made based on the finite element and temperature models. A future modification will upgrade the telescope to use a closed-loop surface metrology system.

The SRT will use a small panel architecture like the GBT (described below). A 32 meter antenna has been outfitted with 244 panels and actuators to prototype the design. These results will be presented by others at this conference. The SRT will not initially use a closed-loop metrology system, but plans are to add a system for the surface control.

GBT

The GBT surface is composed of 2004 relatively small (average of 3.9 m^2/panel) trapezoidal shaped panels--although the merits of correcting the main reflector vs the subreflector and large vs small panels were debated at the outset of the project[5, 6, 7, 8]. These panels are attached to 2209 actuators located at the panel corners[9, 10]. In this configuration, the four neighboring panel corners are attached to a single actuator; thus, the relative corner positions are fixed. This architecture requires a slightly lower density of actuators than the LMT architecture (0.28 vs 0.36 actuators/m^2) and more uniformly distributes the adjustments, while the LMT design allows each subframe to be moved independently.

The individual panels are nominally built to the 60-meter focal length, although there was some economy in the number of molds required [11, 12], with an rms error of 75 microns, when the four corners are properly adjusted. The panels are somewhat flexible in the direction normal to the surface and can survive a runaway actuator displacing a corner by as much as 50 mm out of the plane.

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The 100-meter surface can be thought of as a rubber sheet resting on 2209 points of support. The engineering tradeoff for using only 2209 actuators vs 8016 actuators, in a fully independent panel architecture (four for each panel), is that the fixed corners must be mechanically adjusted and locked in place to a relative accuracy of around 50 microns. This was accomplished by leaving a fiducial point at the corner of each panel unpainted and using these points as field reference points

to the coordinate measurement machine profiles of the panels in the factory. Each panel was uniquely identified by a bar code, which was used by a custom-designed instrument[13, 14] to identify the relative height of each corner, based on the best fit of the coordinate measurement machine profile.

Using state-of-the-art surveying total stations, the actuators were surveyed at the rigging angle. Using another custom-built instrument, the brackets were adjusted to be normal to the surface and aligned radially to the vertex. Then they were welded in place in an absolute coordinate system, within 3 mm of the theoretical coordinates.

After the panels were dropped into place, one panel corner on each actuator was adjusted (using the top accessible adjustment mechanism) to within 6 mm, as measured by the surveying instruments. A photogrammetry target was attached to the master panel at each actuator and the rubber sheet was measured by a single photogrammetry measurement. The photogrammetry accuracy specification was 1 mm rms. All but 52 panels were within the 6 mm specification, and only 23 exceeded 9.5 mm. Those outside the 9.5 mm specification were adjusted and then the relative panel heights of the other three panels were adjusted with the panel setting tool. Panel-to-panel accuracy of around 30 microns rms was achieved. The final construction surface adjustment was made by simply moving the actuators under computer control to achieve the photogrammetry dominated surface accuracy at the rigging angle.

In Phase I operation[15], the GBT has been operated as a fixed surface[16, 17, 18, 19, 20]. The efficiency at the rigging angle, and the actual photogrammetry data, indicate the surface was actually set to about 0.5 mm rms vs the 1 mm expected. Starting with Phase II in March 2002, the surface actuators started correcting the surface as a function of elevation, based on the finite element model, with very good results[21, 22]. Later the surface will be measured by holography on a 0.5 x 0.4-meter pixel spacing, with a goal of 0.100 mm accuracy at several elevations[23]. Due to the small panel/rubber sheet architecture, it is expected that the holography adjustments will all be made by the actuators, although some local defects may be resolved and small manual relative adjustments may need to be made between panel corners.

In Phase III, the surface will be measured by laser ranging instruments[24, 25, 26, 27, 28, 29] mounted on the feed arm looking down on the surface. This will provide for closed-loop corrections for gravitational and thermal deflections. Retroreflectors have been calibrated and mounted in the corner adjustment hole of one panel at each actuator[30]. The retroreflector mounts are also referenced to the coordinate measurement machine, so the laser ranging instruments will be referenced to the reflector surface in an absolute system, i.e., the laser measurements will not depend on holography for a reference.

The feed arm laser ranging instruments will also tie to 12 stable, ground -based, laser ranging instruments, at a radius of 120 meters. The location of the 12 ground instruments have been surveyed to better than 0.030 mm in the vertical direction, with respect to the local gravity vector[31, 32]. By tying the best fit paraboloid to the ground instruments, the absolute pointing of the main reflector is derived from first principles[33, 34, 35, 36].

While the metrology systems for the LMT and SRT will be a later modification, and therefor the designs are not yet fixed, there are no plans to tie the reflector surface to an absolute ground coordinate system, and thus the GBT metrology architecture is unique in that capability.

An additional feature of the metrology system is a network of retroreflectors located at cardinal points on the structure. Measurements of these cardinal points will be used to monitor the performance and health of the complex structure[37], as well as provide feedback to the structural and pointing models.

The next ten years should prove to be interesting as these telescopes push to meet their goals.

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